Future Plans at Jefferson Lab: 12 GeV Upgrade and ELIC

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DIS 2007
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OUTLINE

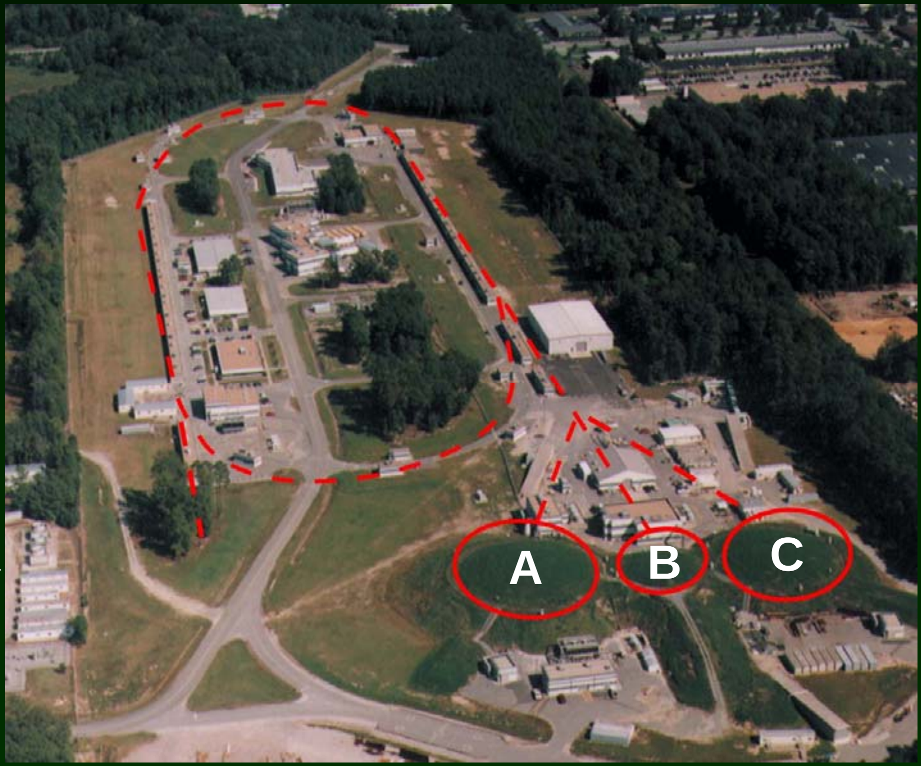
- 12 GeV Upgrade:
  - Jefferson Lab Today and Tomorrow
  - Highlights of Science Program
  - Project Status

- ELIC:
  - Jefferson Lab Science Beyond 12 GeV Upgrade
  - Design Approach
  - Next Steps

Jefferson Lab Today

2000 member international user community engaged in exploring quark-gluon structure of matter

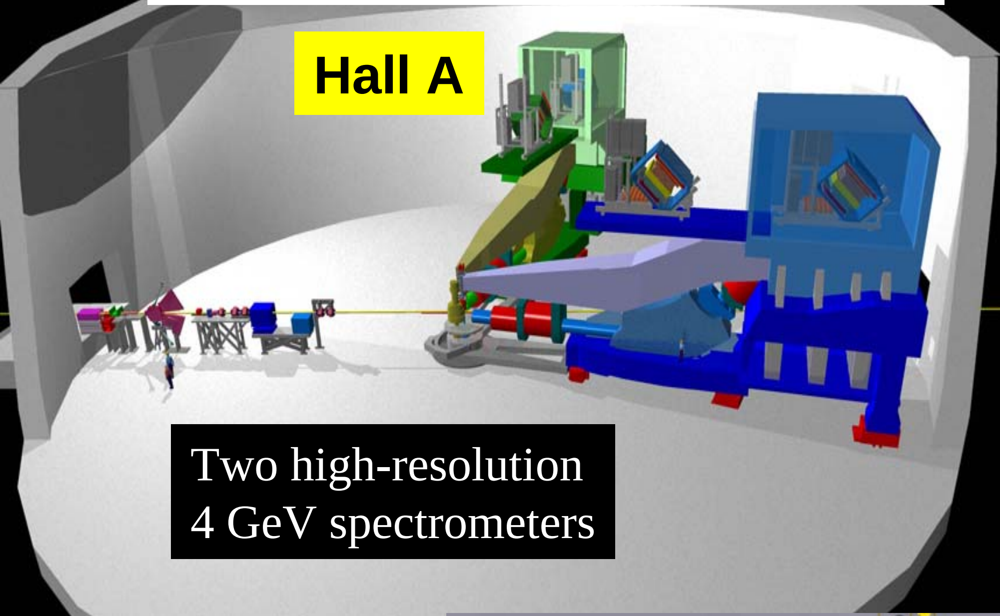
Superconducting accelerator provides 100% duty factor beams of unprecedented quality, with energies up to 6 GeV

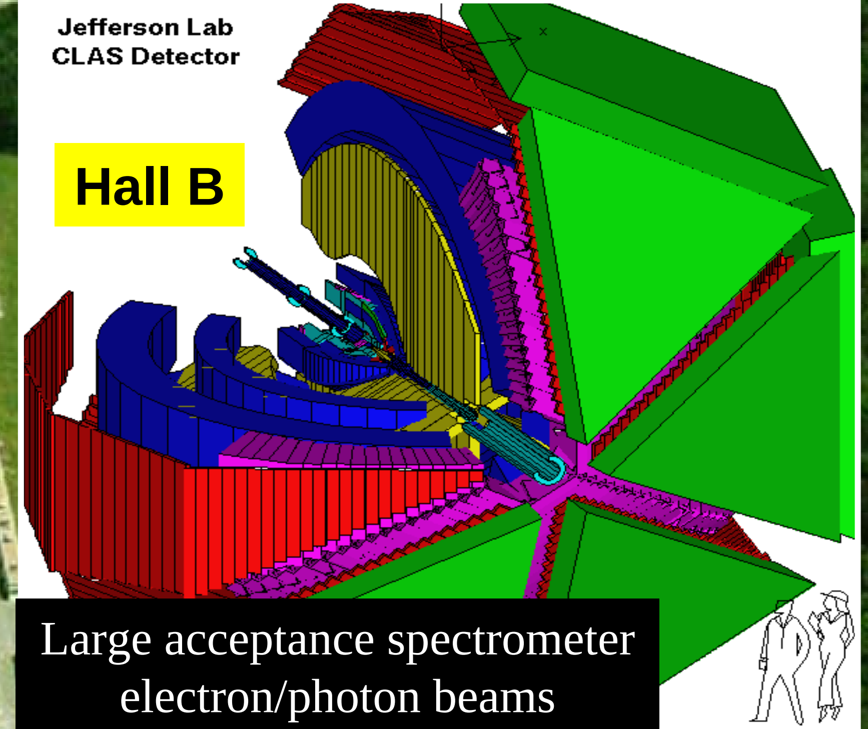


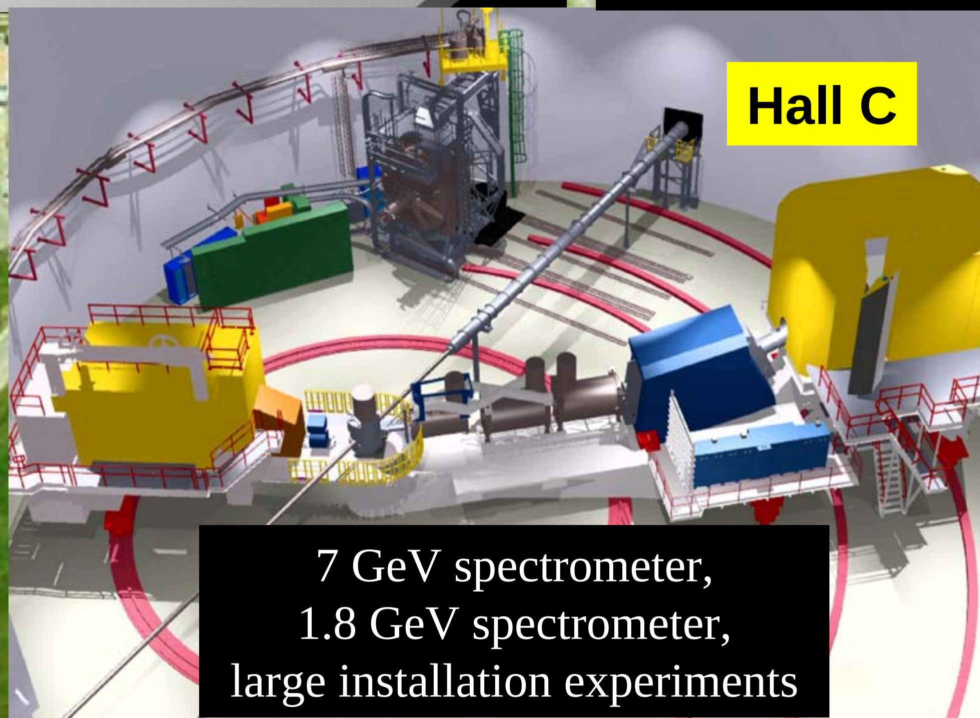
CEBAF's innovative design allows delivery of beam with unique properties to three experimental halls simultaneously

Each of the three halls offers complementary experimental capabilities and allows for large equipment installations to extend scientific reach

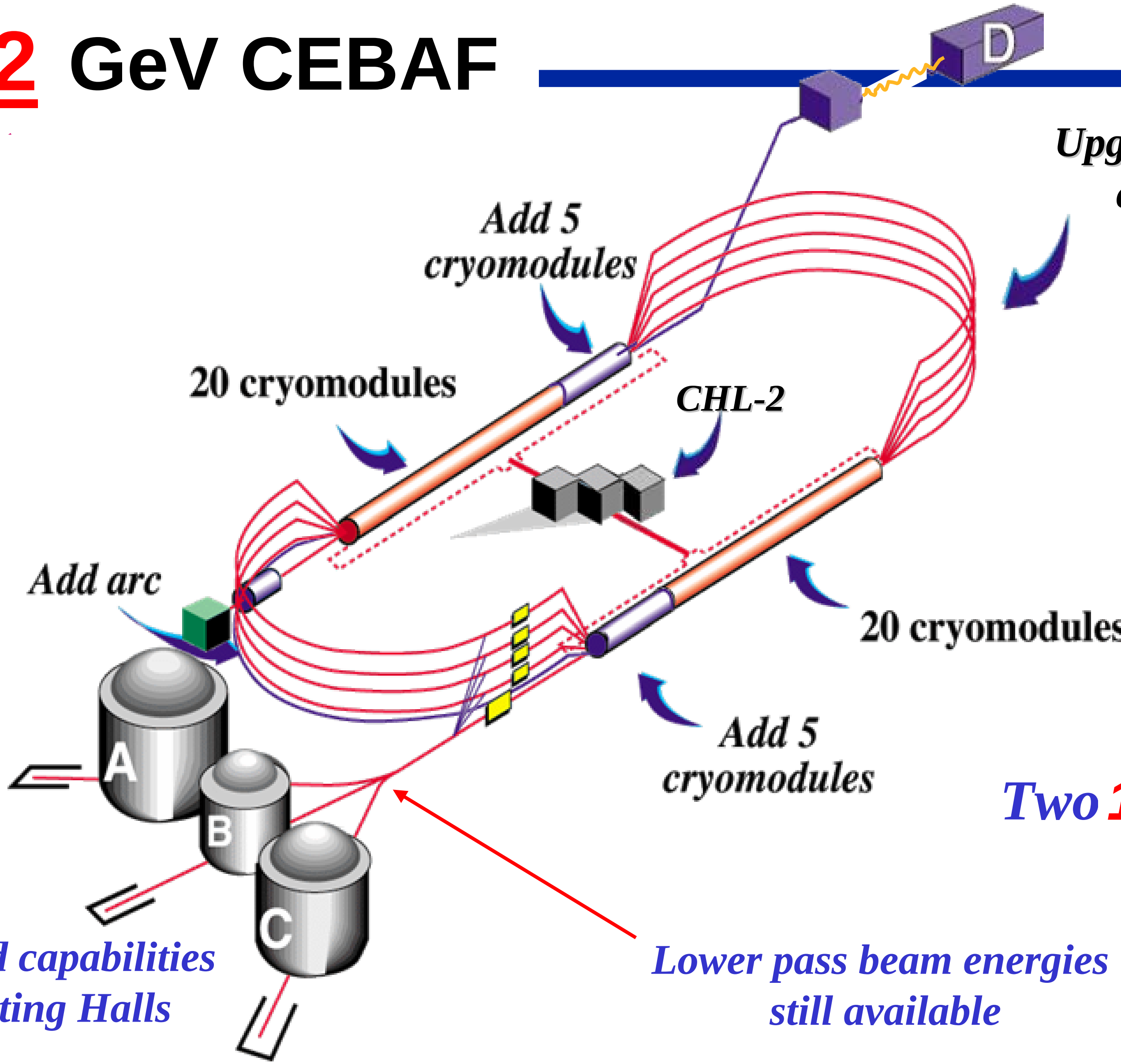
Jefferson Lab Today







12 GeV CEBAF

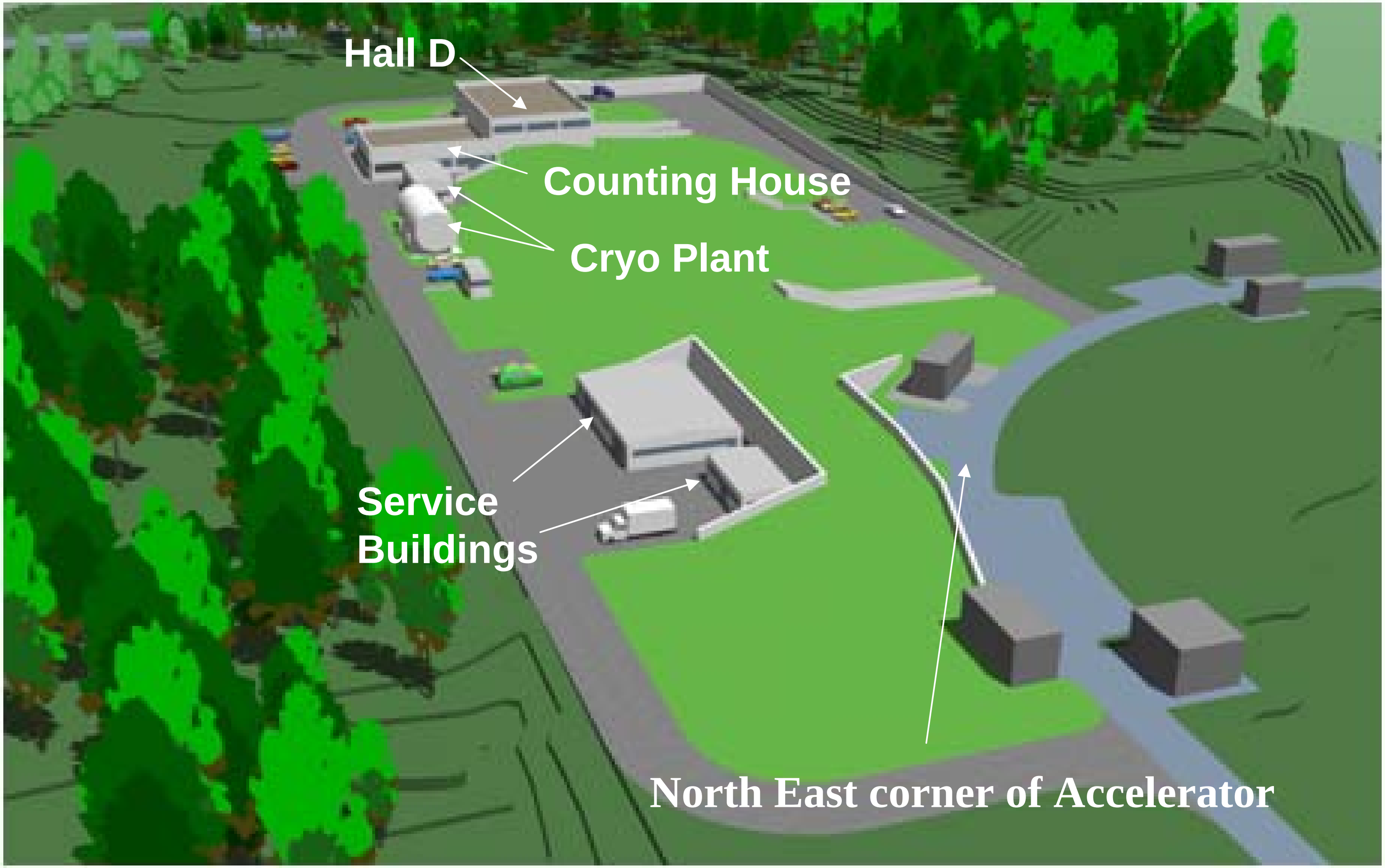


*Two **1.1** GV linacs*

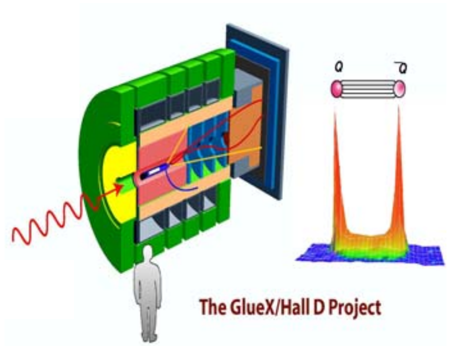
Enhanced capabilities in existing Halls

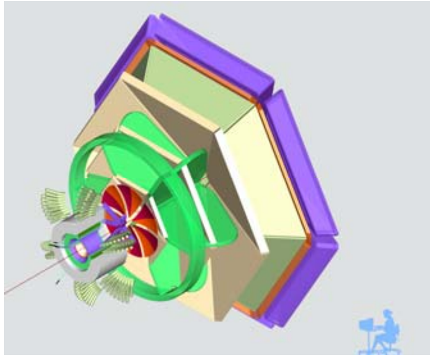
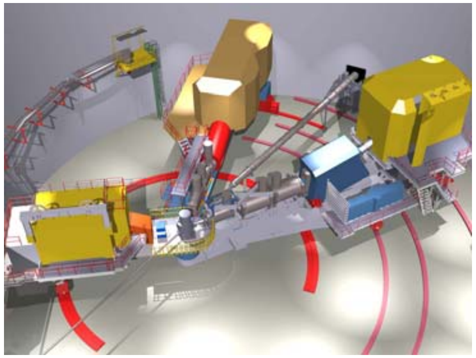
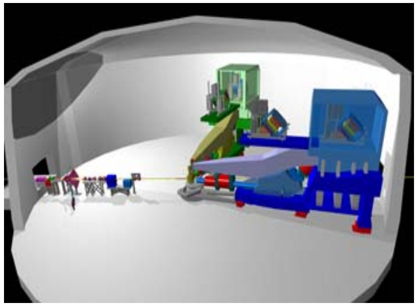
Lower pass beam energies still available

Architect's Rendering of Hall D Complex



Overview of Upgrade Technical Performance Requirements



<table>
<tr><th>Hall D</th><th>Hall B</th><th>Hall C</th><th>Hall A</th></tr>
<tr><td>excellent hermeticity</td><td>luminosity 10×10^{34}</td><td>energy reach</td><td>installation space</td></tr>
<tr><td>polarized photons</td><td>hermeticity</td><td>precision</td><td></td></tr>
<tr><td>$E_\gamma \sim 8.5–9$ GeV</td><td colspan="3">11 GeV beamline</td></tr>
<tr><td>10^8 photons/s</td><td colspan="3">target flexibility</td></tr>
<tr><td colspan="2">good momentum/angle resolution</td><td colspan="2">excellent momentum resolution</td></tr>
<tr><td colspan="2">high multiplicity reconstruction</td><td colspan="2">luminosity up to 10^{38}</td></tr>
<tr><td colspan="4">particle ID</td></tr>
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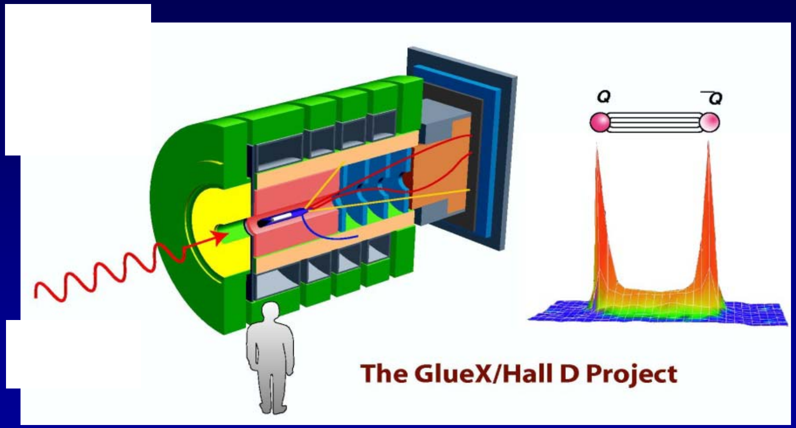
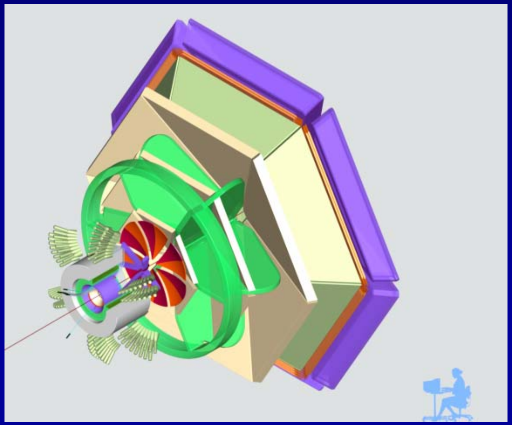
12 GeV Capabilities

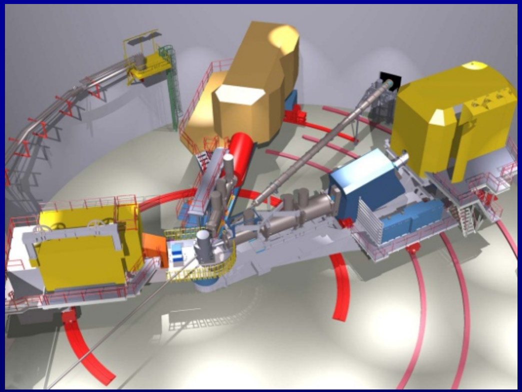
Hall D – exploring origin of confinement by studying exotic mesons

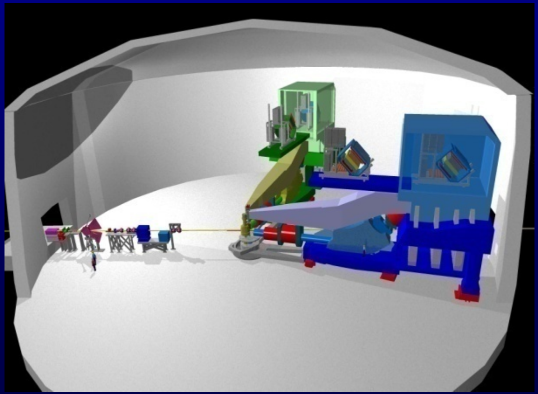




Hall B – understanding nucleon structure via generalized parton distributions

Hall C – precision determination of valence quark properties in nucleons and nuclei





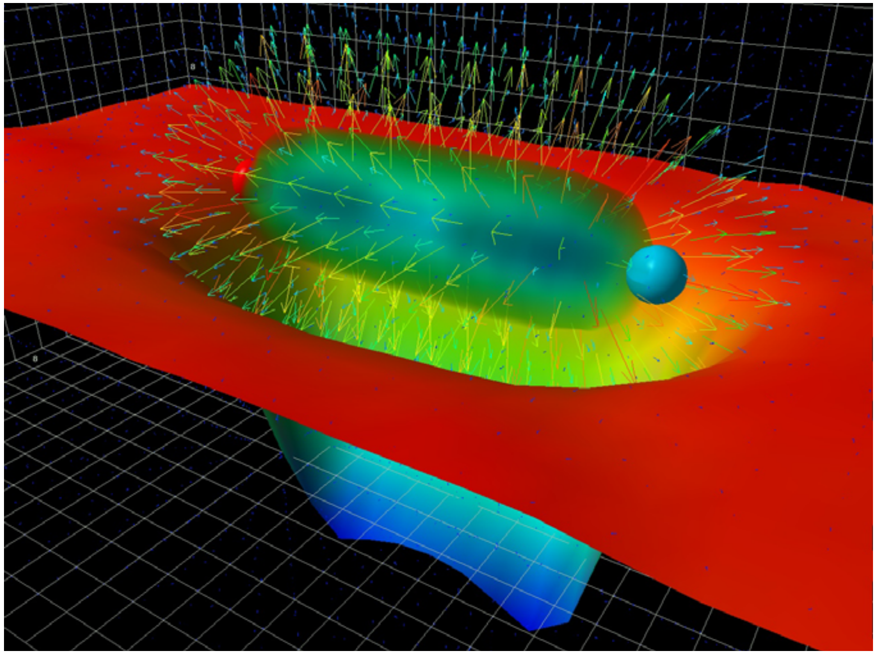
Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments

Highlights of the 12 GeV Science Program

- Unlocking secrets of QCD: quark confinement
- New and revolutionary access to the structure of the proton and neutron
- Discovering the quark structure of nuclei
- High precision tests of the Standard Model

DIS 2007 Talks:
Antje Bruell
Zein-Eddine Meziani
Krishna Kumar

Gluonic Excitations and the Origin of Confinement

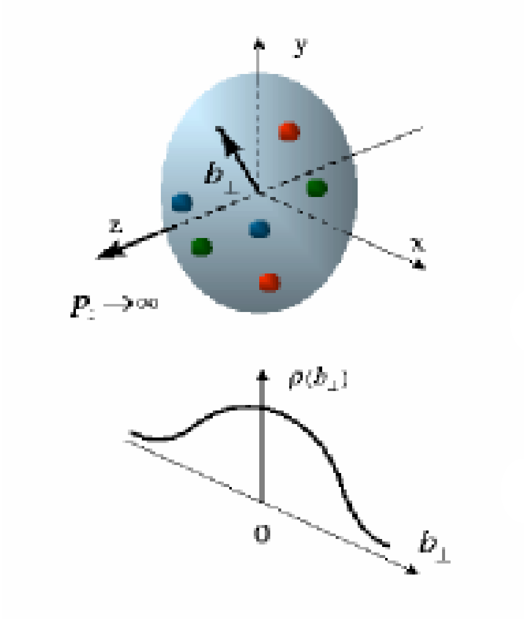


QCD predicts a rich spectrum of as yet to be discovered gluonic excitations - whose experimental verification is crucial for our understanding of QCD in the confinement regime.

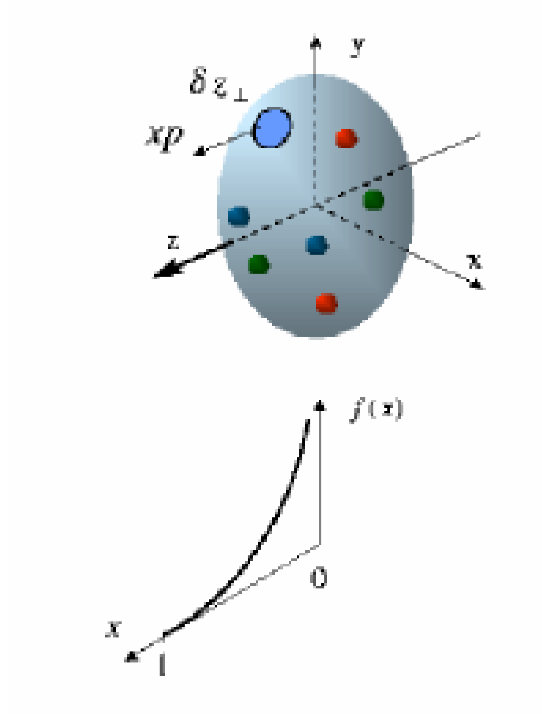
With the upgraded CEBAF, a linearly polarized photon beam, and the GlueX detector, Jefferson Lab will be <u>uniquely poised</u> to:

- **discover these states,**
- **map out their spectrum, and**
- **measure their properties**

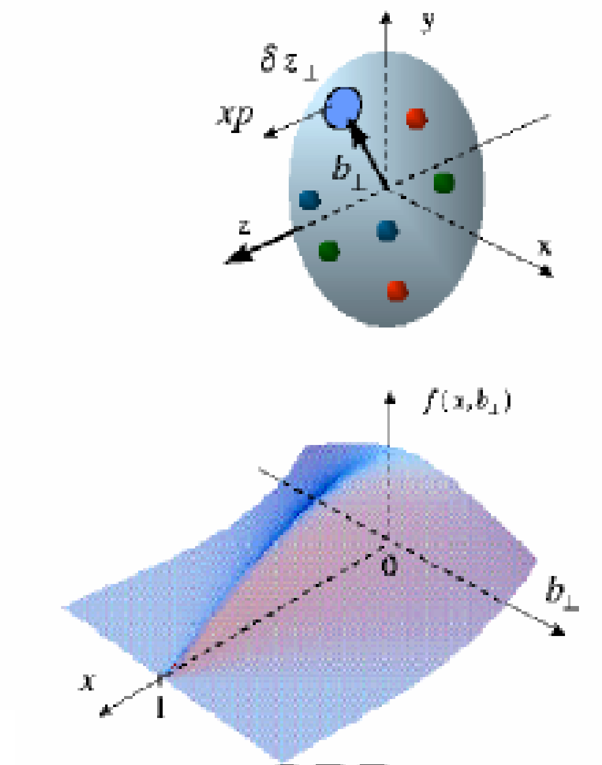
New, comprehensive view of hadronic structure



Elastic Scattering
transverse quark distribution in Coordinate space



DIS
longitudinal quark distribution in momentum space

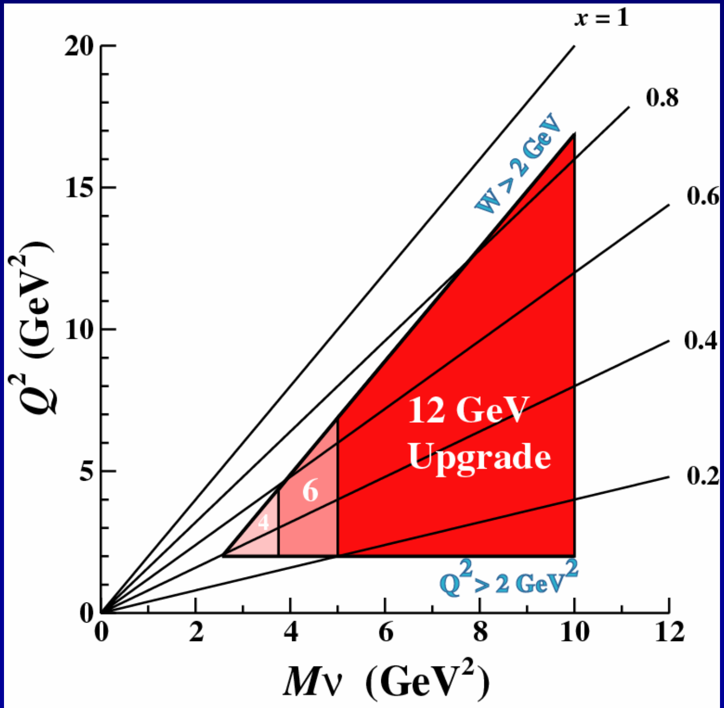


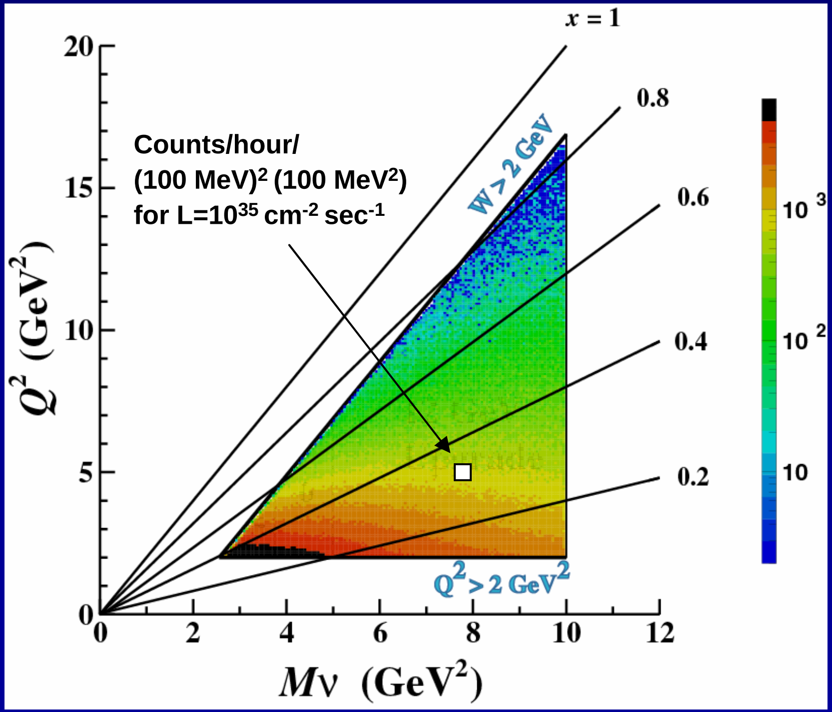
GPDs
The fully-correlated Quark distribution in both coordinate and momentum space

Quark Structure of Nuclei

- (Nucleons and Pions) or (Quarks and Gluons)?
- Not a simple convolution of free nucleon structure with Fermi motion
- In nuclear deep-inelastic scattering, we look directly at the quark structure of nuclei

12 GeV Upgrade Provides Substantially Enhanced Access to the DIS Regime

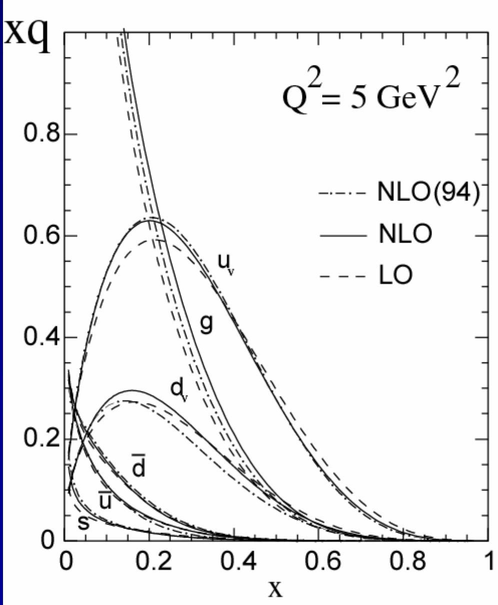


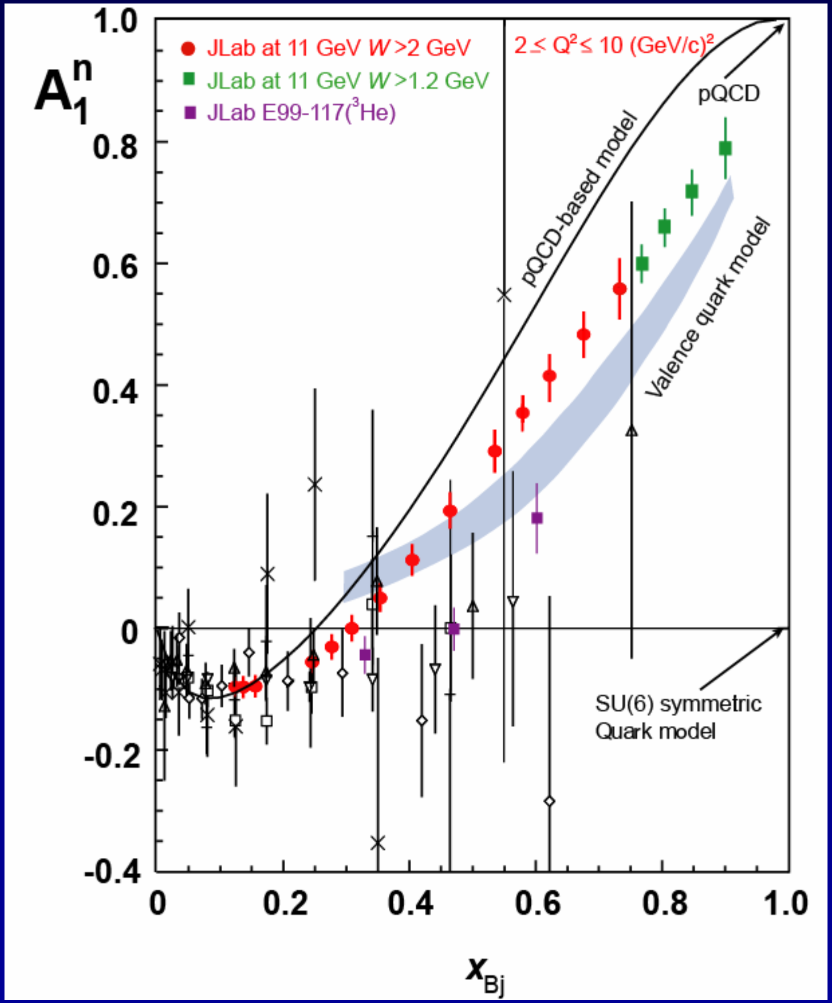


Measuring High-x Structure Functions

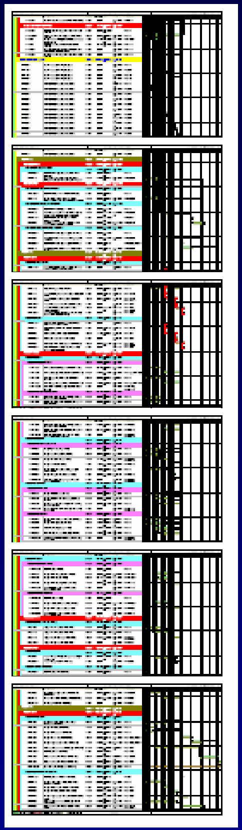
REQUIRES:

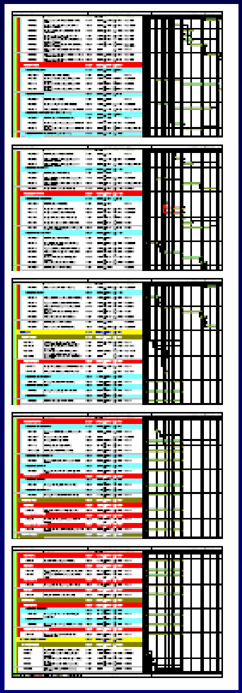
- High beam polarization
- High electron current
- High target polarization
- Large solid angle spectrometers



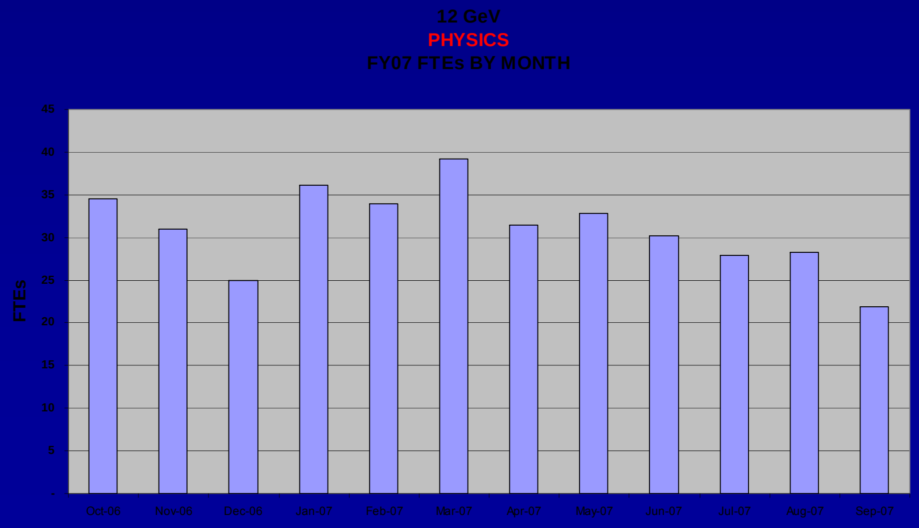


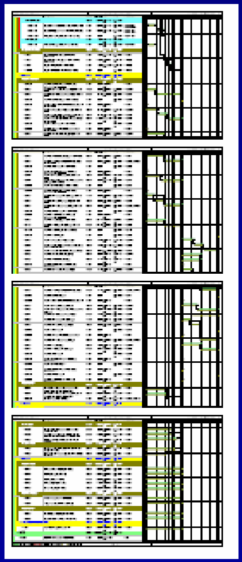
12 GeV will access the regime (x > 0.3), where valence quarks dominate





The 12 GeV Upgrade Project: Status and Schedule





DOE Generic Project Timeline

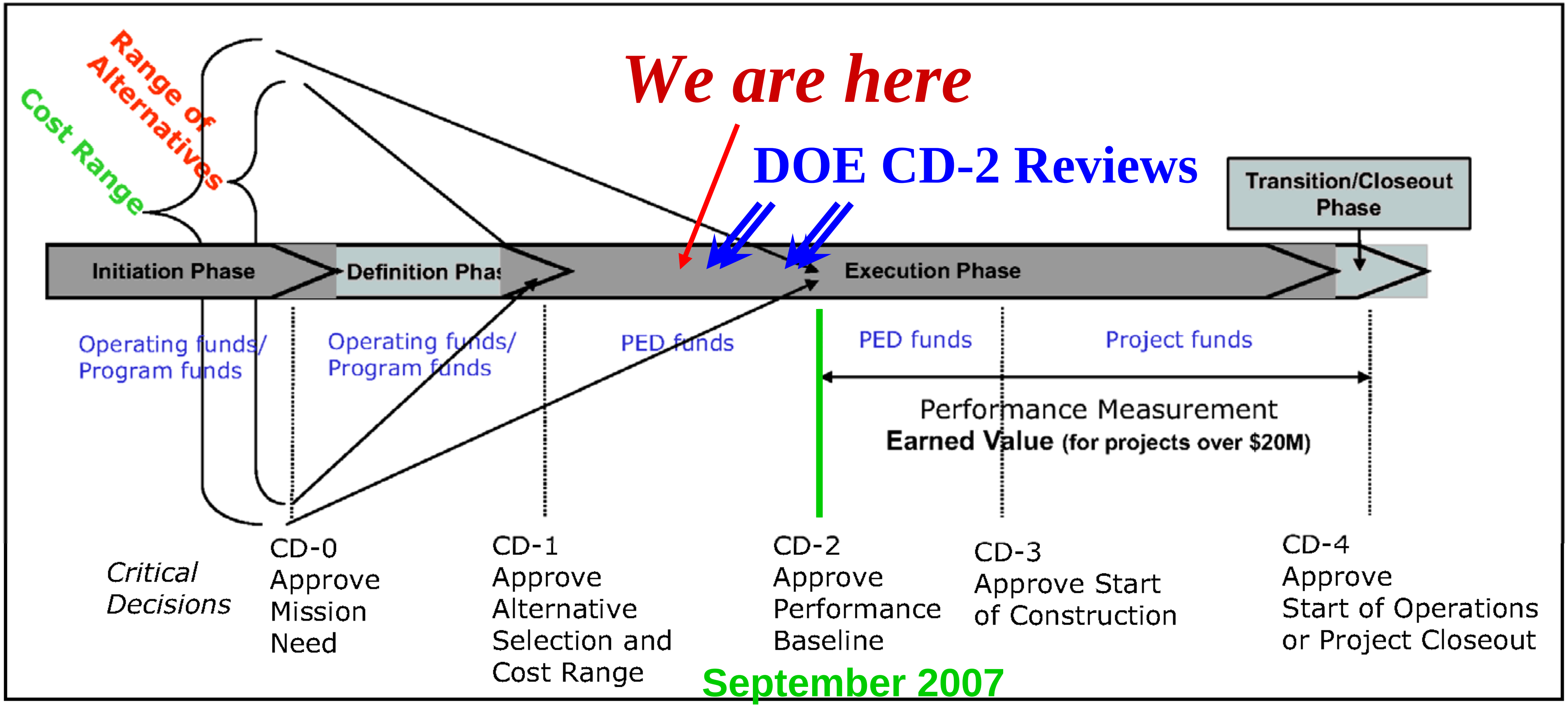


Figure 1-1. DOE Acquisition Management System.

12 GeV Upgrade: Phases and Schedule

(based on funding guidance provided by DOE-NP in March 2007)

- 2004-2005 Conceptual Design (CDR) - ***finished***
- 2004-2008 Research and Development (R&D) - ***ongoing***
- 2006 Advanced Conceptual Design (ACD) - ***finished***
- 2006-2008 Project Engineering & Design (PED) - ***ongoing***
- 2009-2013 Construction – ***starts in ~18 months!***
  - ***Accelerator shutdown start mid 2012***
  - ***Accelerator commissioning mid 2013***
- 2013-2015 Pre-Ops (beam commissioning)
  - ***Hall commissioning start late 2013***

CD-2 → September '07

- December & January: DOE Project Status Review
  - "The 12 GeV Upgrade Project is on track in their preparations and readiness for the SC IPR, OECM EIR and September 2007 CD-2 approval."
- June 26-28: Critical Decision 2 Review, stage I
  - SC Independent Project Review (IPR): conducted by Dan Lehman (DOE SC Office of Project Assessment)
- Aug 6-10 (tentative): Critical Decision 2 Review, stage II
  - External Independent Review (EIR): conducted by DOE Office of Engineering Construction Management (OECM)
- Aug 6-10: JLab PAC32
  - Second review of 12 GeV proposals – "commissioning experiments"
  - Key step in identifying the research interests and contributions of international collaborators

12 GeV Upgrade Summary

- Essential to address key questions in hadronic physics
  - Broad and diverse scientific program
  - Unique and complementary kinematic reach and capabilities
  - Strong opportunity for international collaboration

- 12 GeV Project: Construction start in ~18 months
  - Critical Decision 2 in September 2007 (baseline)
  - Critical Decision 3 in September 2008 (construction start)
  - We are on track for accomplishing this!

ELIC: Science Motivation

A High Luminosity, High Energy Electron-Ion Collider:
A New Experimental Quest to Study the Glue which Binds Us All

How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?

Explore the new QCD frontier: strong color fields in nuclei:

- **How do the gluons contribute to the structure of the nucleus?**
- **What are the properties of high density gluon matter?**
- **How do fast quarks or gluons interact as they traverse nuclear matter?**

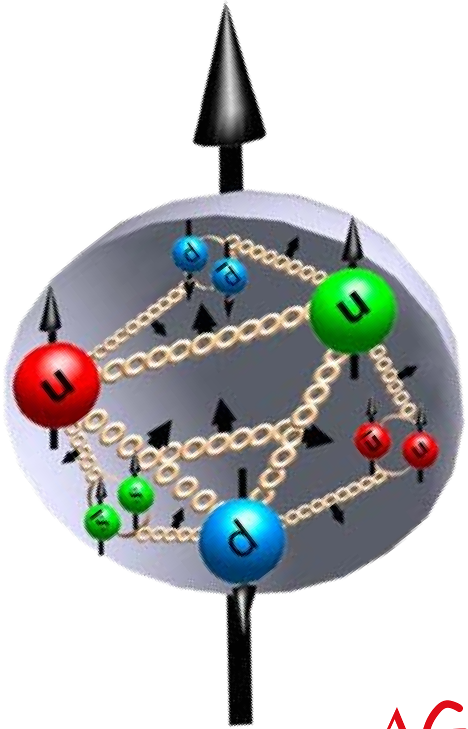
Precisely image the sea-quarks and gluons in the nucleon:

- **How do the gluons and sea-quarks contribute to the spin structure of the nucleon?**
- **What is the spatial distribution of the gluons and sea quarks in the nucleon?**
- **How do hadronic final-states form in QCD?**

DIS2007 Talks:
Antje Bruell
Bernd Surrow

The Spin Structure of the Nucleon

Proton helicity sum rule:



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

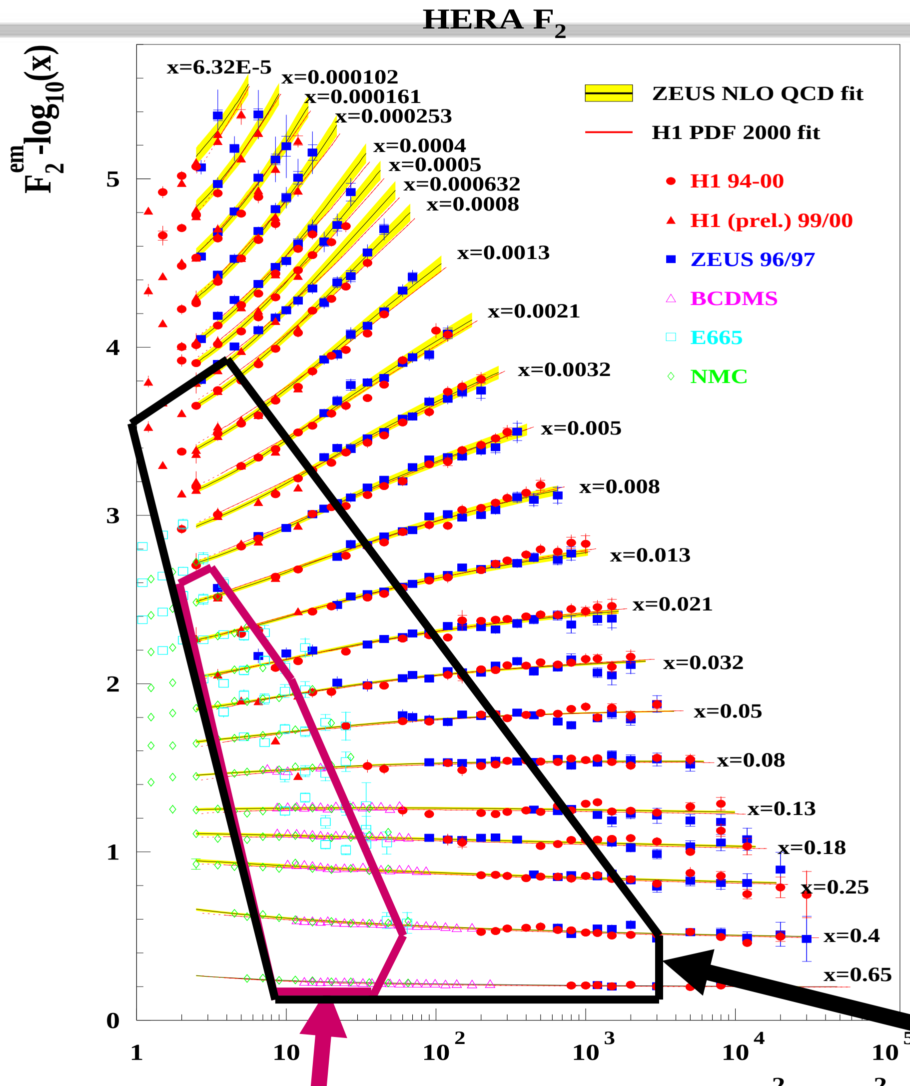
We know from lepton scattering experiments over the last three decades that:

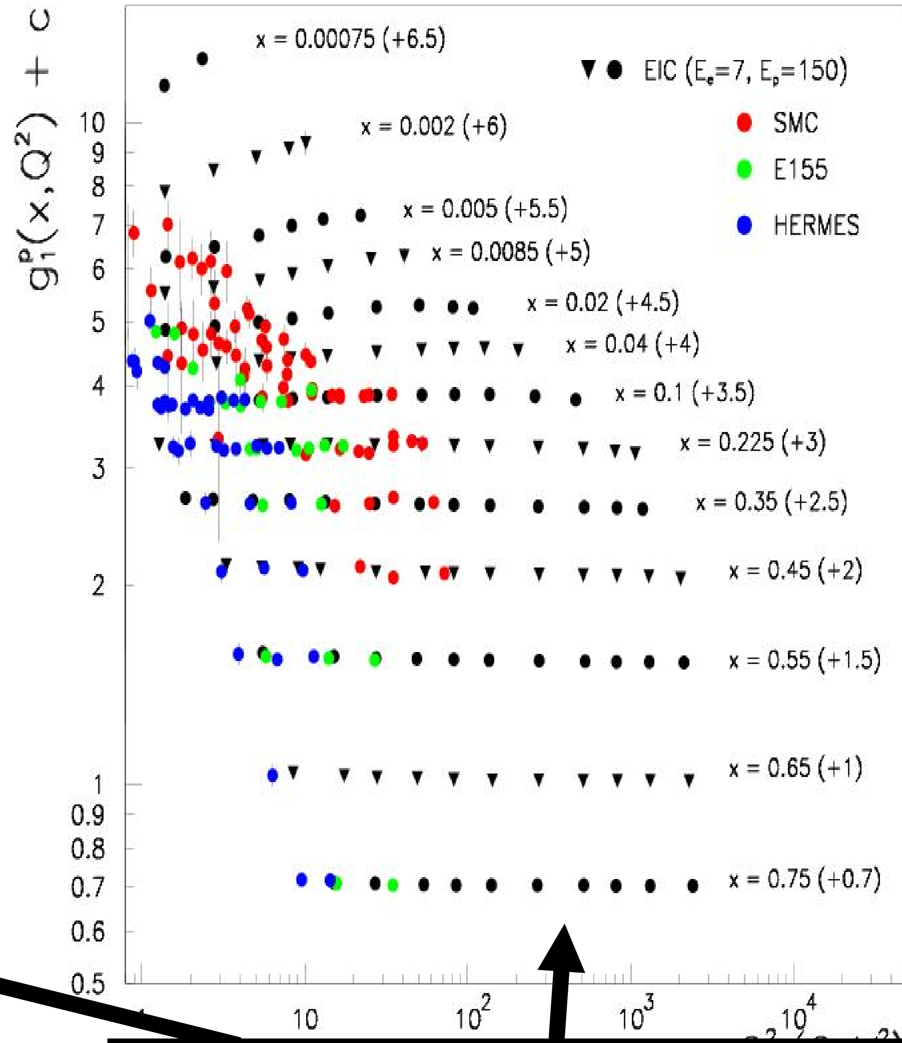
- quark contribution $\Delta\Sigma \approx 0.3$
- gluon contribution $\Delta G \approx 1 \pm 1$
- valence quark polarizations as expected
- measured anti-quark polarizations are consistent with zero

ΔG: a "quotable" property of the proton (like mass, momentum contrib., ...)

(However, Q^2 dependent: $\Delta G(Q^2) \propto \dfrac{1}{\alpha_s(Q^2)}$)

World Data on F_2^p World Data on g_1^p





Region of existing g_1^p data

An EIC makes it possible!

ELIC Study Group & Collaborators

A. Afanasev, A. Bogacz, P. Brindza, A. Bruell, L. Cardman, Y. Chao, S. Chattopadhyay, E. Chudakov, P. Degtiarenko, J. Delayen, Ya. Derbenev, R. Ent, P. Evtushenko, A. Freyberger, D. Gaskell, J. Grames, A. Hutton, R. Kazimi, G. Krafft, R. Li, L. Merminga, J. Musson, M. Poelker, R. Rimmer, A. Thomas, H. Wang, C. Weiss, B. Wojtsekhowski, B. Yunn, Y. Zhang - Jefferson Laboratory

W. Fischer, C. Montag - Brookhaven National Laboratory

V. Danilov - Oak Ridge National Laboratory

V. Dudnikov - Brookhaven Technology Group

P. Ostroumov - Argonne National Laboratory

V. Derenchuk - Indiana University Cyclotron Facility

A. Belov - Institute of Nuclear Research, Moscow-Troitsk, Russia

V. Shemelin - Cornell University

ELIC Accelerator Design Goals

- **Center-of-mass energy between 20 GeV and 90 GeV:**
  with energy asymmetry of ~10, which yields
  (E_e ~ 3 GeV on E_A ~ 30 GeV) up to (E_e ~ 9 GeV on E_A ~ 225 GeV)

- **Average Luminosity from 10^{33} to 10^{35} cm^{-2} sec^{-1} per Interaction Region**

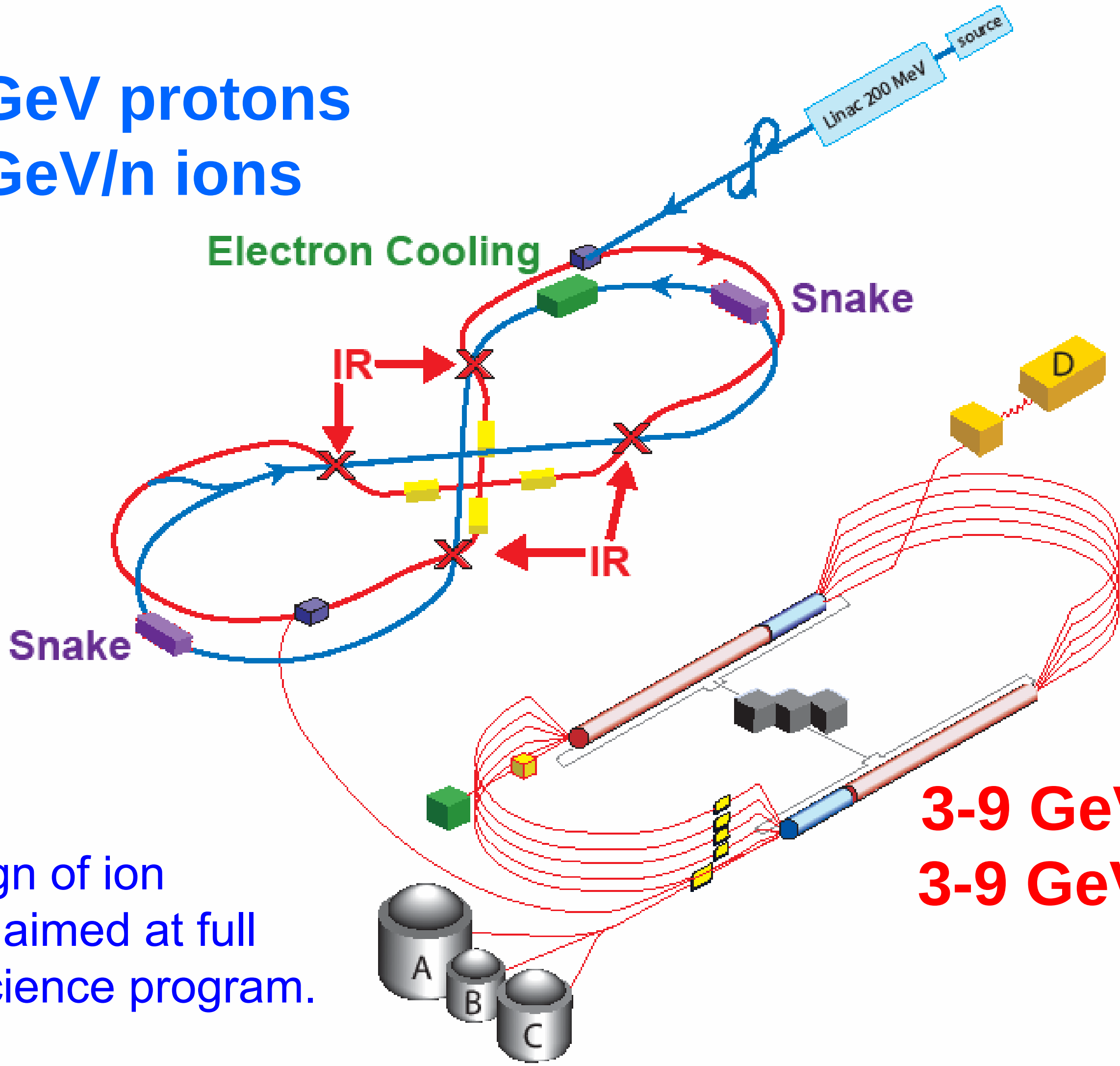
- **Ion Species:**
  - Polarized H, D, ^{3}He, possibly Li
  - Ions up to A = 208

- **Polarization:**
  - Longitudinal for both beams in the interaction region
  - Transverse polarization of ions
  - Spin-flip of both beams
  - All polarizations >70% desirable

- **Positron Beam desirable**

ELIC Layout

30-225 GeV protons
30-100 GeV/n ions



3-9 GeV electrons
3-9 GeV positrons

Green-field design of ion complex directly aimed at full exploitation of science program.

Design Features of ELIC

Directly aimed at optimizing the science program:

- Ring-Ring design where 12 GeV CEBAF accelerator serves as injector to electron ring.
- Unprecedented luminosity through short ion bunches, low β*, and high rep rate (crab crossing).
- Four interaction regions for high productivity ([± 3 m] element-free region around the IP's).
- Polarized positron beam possible as well as e^-e^- colliding beams.
- Present JLab DC polarized electron gun meets beam current requirements for filling storage ring.
- Collider operation appears compatible with *simultaneous* 12 GeV CEBAF operation for fixed target program.

Accelerator R&D Required for ELIC

To achieve luminosity at ~ 10^{33} cm^{-2} sec^{-1}

- High energy electron cooling with circulator ring

To achieve luminosity at ~ 10^{35} cm^{-2} sec^{-1}

- Crab crossing
- Stability of intense ion beams
- Beam-beam interactions
- High RF frequency (part of detector R&D)

ELIC Summary

- A compelling scientific case is developing for an electron ion collider to address fundamental questions in hadronic physics.
  - Complements definitive study of valence region at JLab 12 GeV

- JLab design studies have led to:
  - Ring-Ring approach that uses CEBAF as a full energy e- injector and can be integrated with the 12 GeV fixed target program for physics
  - Includes heavy ions, $20 < E_{CM} < 90$ GeV
  - L_p at or above 10^{35} cm^{-2}s^{-1} (per nucleon) possible
  - L_p up to 10^{33} cm^{-2}s^{-1} can be achieved with state-of-the-art technology, except for electron cooling

- JLab is committed to collaborative approach for developing science case and optimal technical design for a next generation EIC.

- A pre-R&D plan to address EIC accelerator physics and technology issues has been developed, and hopefully will be included in the NSAC LRP.

ELIC
BACKUP TRANSPARENCIES

ELIC Recent Developments

ELIC design evolves

- in response to Science requirements (e.g. Rutgers mtg.)
- towards a more robust and reliable concept which relies increasingly on proven state-of-the-art technology.

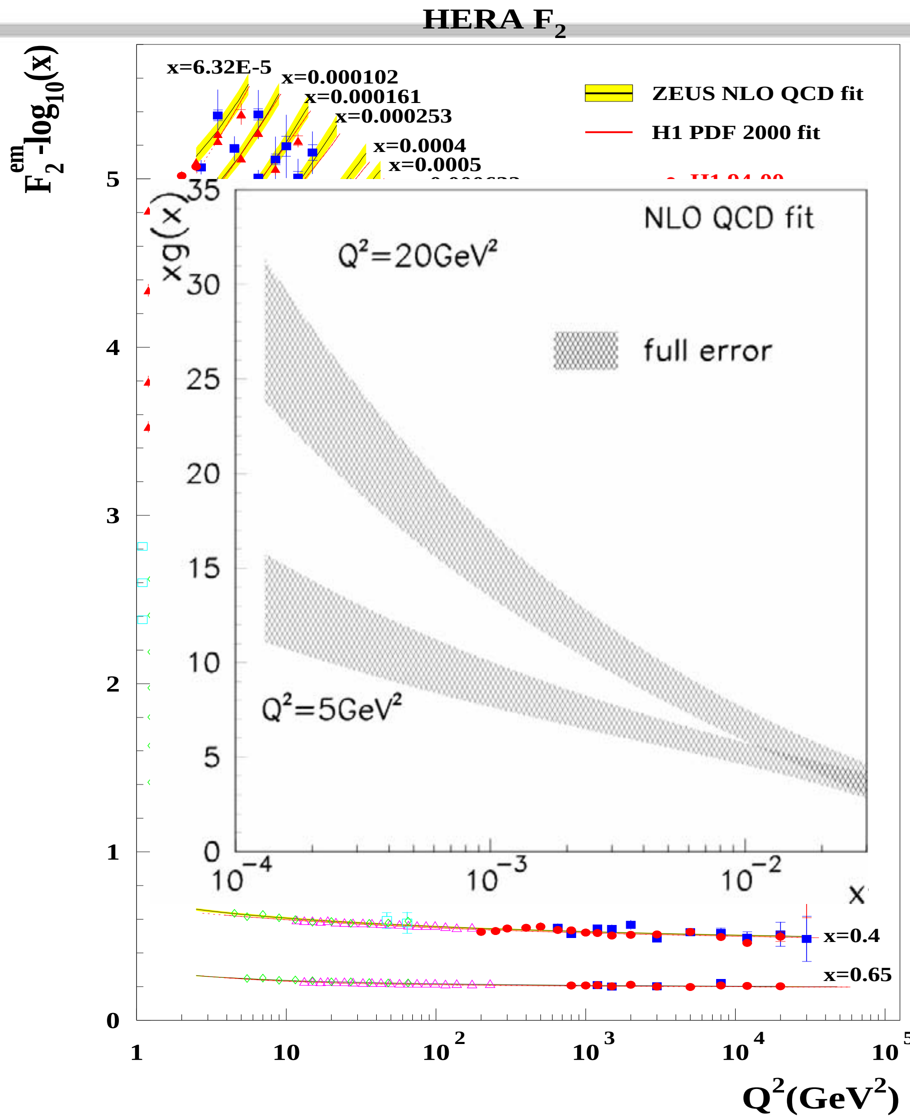
Recent developments include:

- Higher center-of-mass energy and inclusion of heavy ions, up to Pb
- Concept of SRF ion linac for all ions (ANL design)
- The use of stochastic cooling to accumulate intense ion beam
- Reducing crab cavity voltage requirement by decreasing crossing angle from 100 mrad to 50 mrad and in combination with a new Lambertson-type final focus quadrupole
    - Longer [± 3 m] element-free region around the IP's

Advantages/Features of ELIC

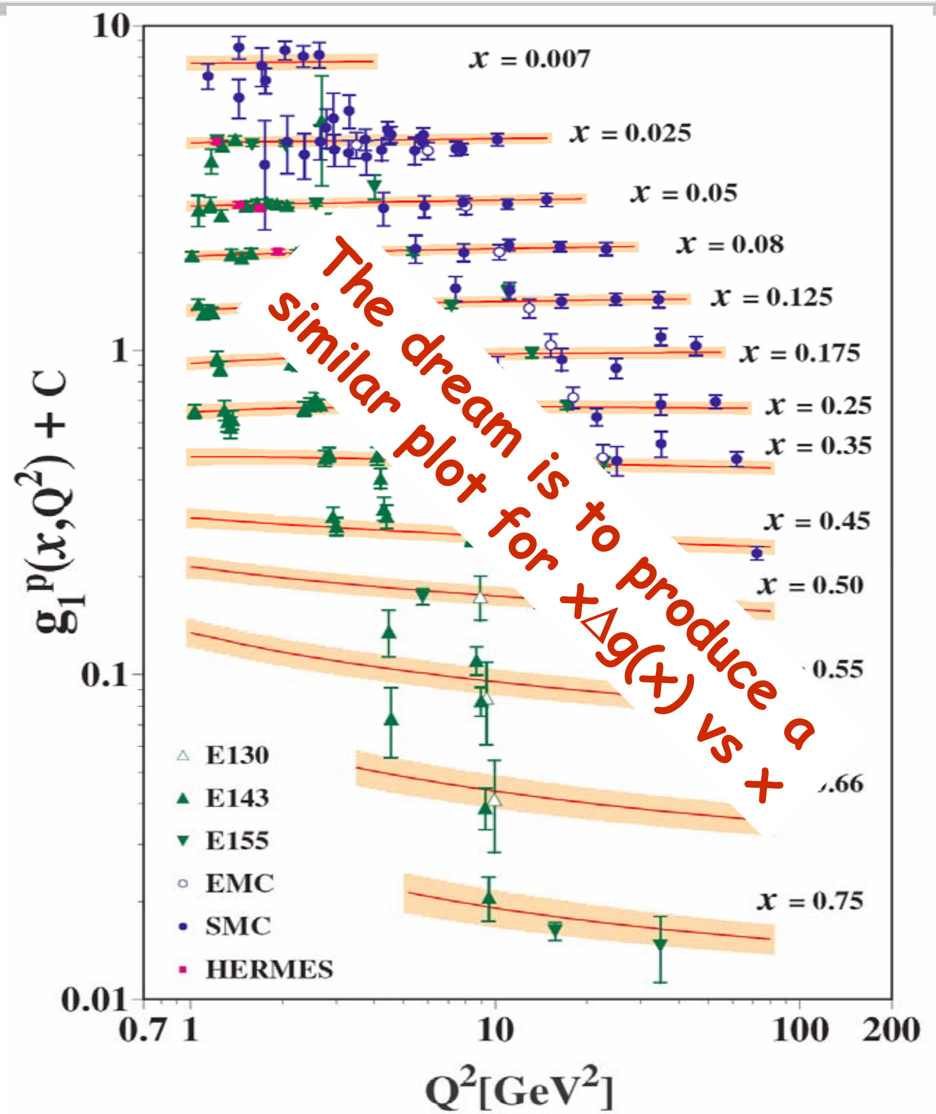
- JLab DC polarized electron gun already meets beam current requirements for filling the storage ring.
- A conventional kicker already in use in many storage rings would be sufficient.
- The 12 GeV CEBAF accelerator can serve as an injector to the ring. RF power upgrade might be required later depending on the performance of ring.
- Physics experiments with polarized positron beam are possible.
- Possibilities for e^+e^-, e^-e^-, e^+e^+ colliding beams.
- No spin sensitivity to energy and optics.
- No orbit change with energy despite spin rotation.
- Collider operation appears compatible with *simultaneous* 12 GeV CEBAF operation for fixed target program.

World Data on F_2^p



→ 50% of momentum carried by gluons

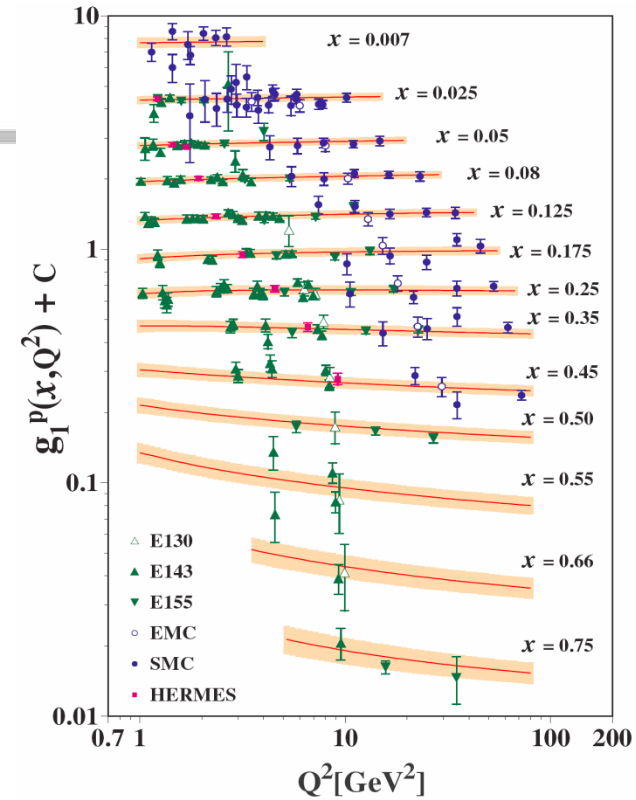
World Data on g_1^p



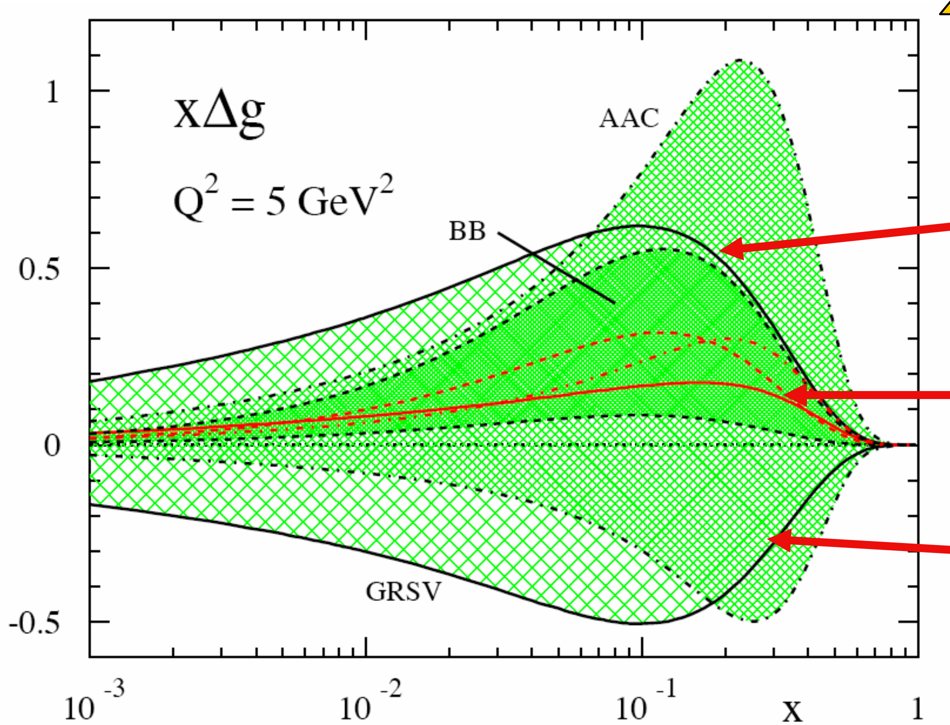
→ 20% of proton spin carried by quark spin

The Quest for ΔG

First approach: use scaling violations of world g_1 spin structure function measurements



Not enough range in x and Q^2



$$\Delta G(1\,\mathrm{GeV}^2) \approx 1.8$$

$$\Delta G(1\,\mathrm{GeV}^2) \approx 0.4$$

$$\Delta G(1\,\mathrm{GeV}^2) \approx -1.7$$

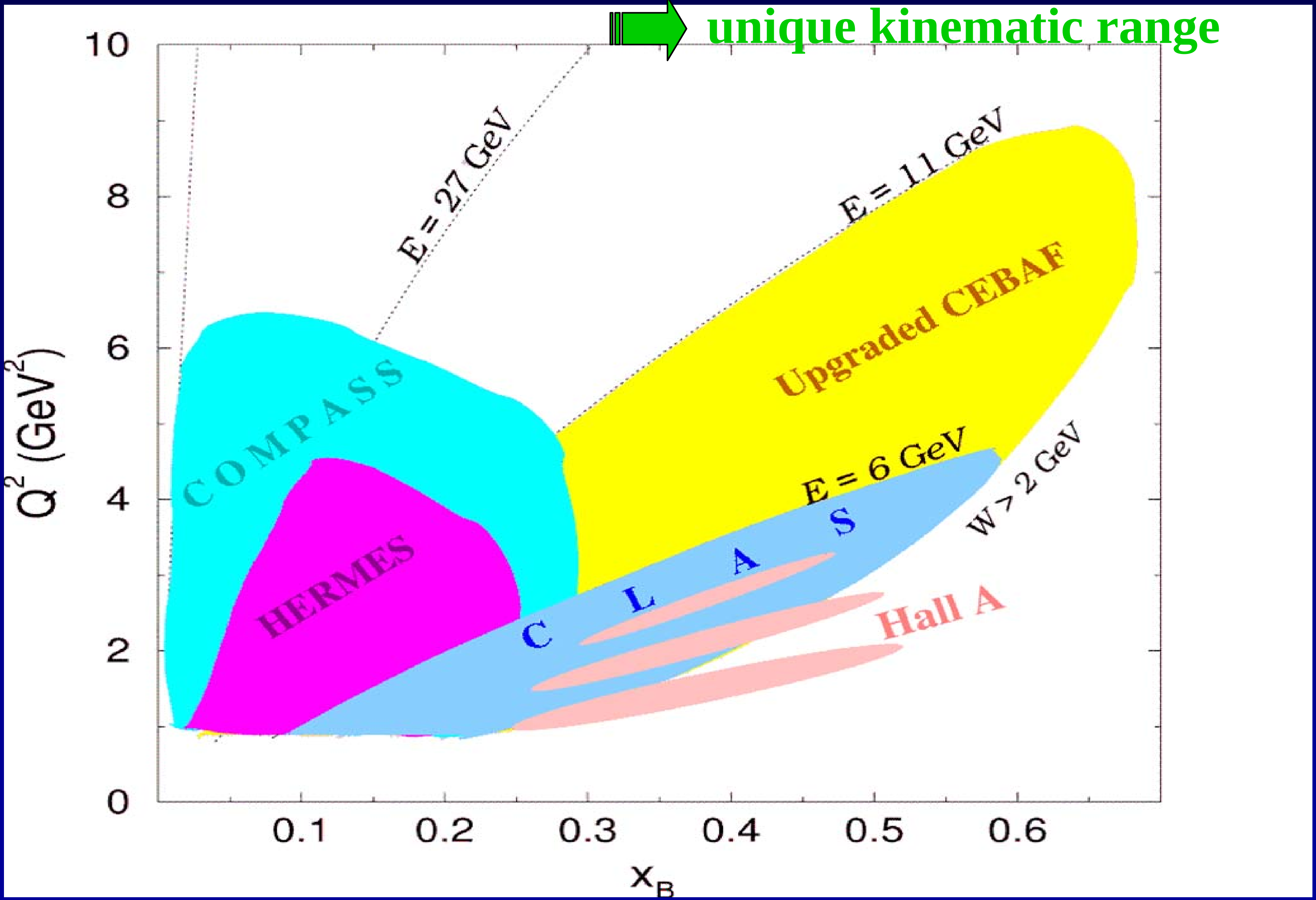
12 GeV BACK - UP

High-level Parameters

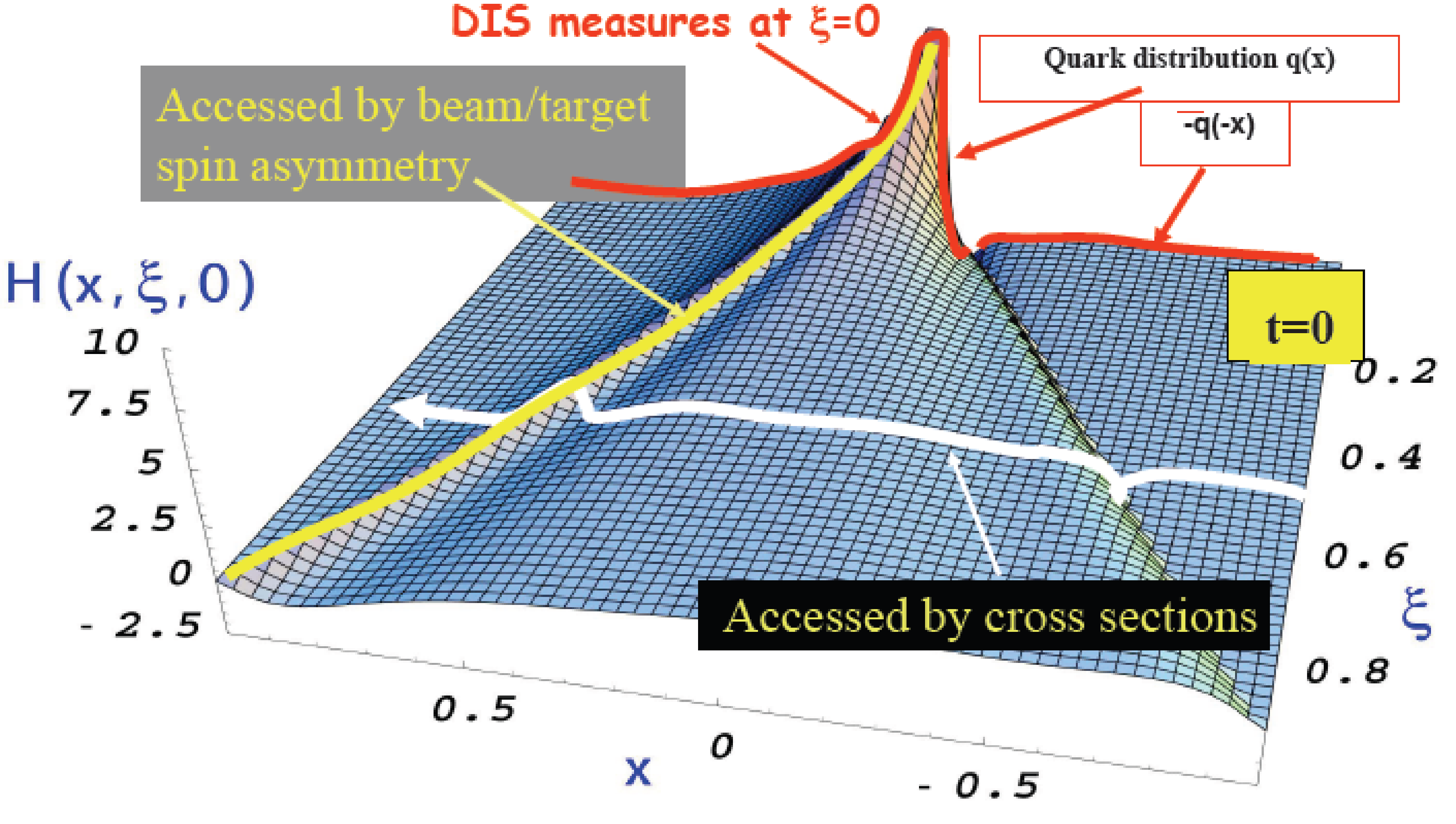
Beam energy	12 GeV
Beam power	1 MW
Beam current (Hall D)	5 μA
Emittance @ 12 GeV	10 nm-rad
Energy spread @ 12 GeV	0.02%
Simultaneous beam delivery	Up to 3 halls

Kinematics for deeply exclusive experiments

unique kinematic range



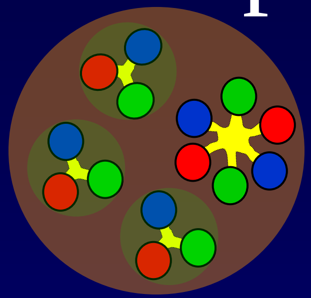
GPDs via cross sections and asymmetries



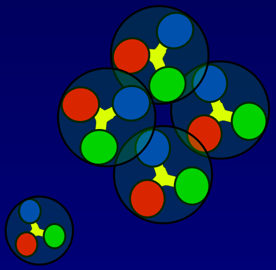
EMC Effect - Theoretical Explanations

Quark picture

- Multi-quark cluster models
  - Nucleus contains multinucleon clusters (e.g., 6-quark bag)

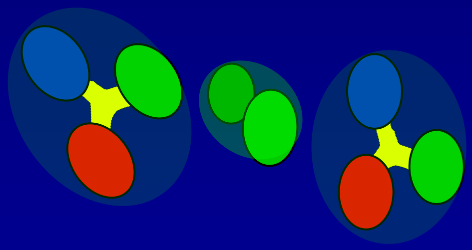


- Dynamical rescaling
  - Confinement radius larger due to proximity to other nucleons

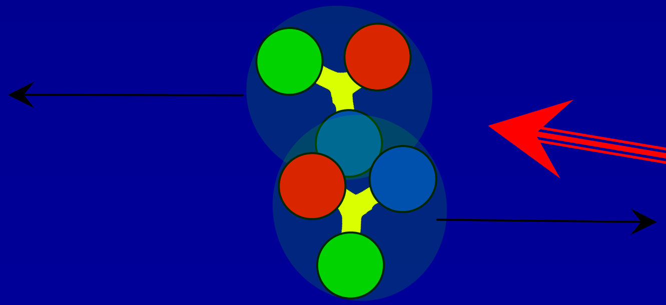


Hadron picture

- Nuclear binding
  - Effects due to Fermi motion and nuclear binding energy, including virtual pion exchange



- Short range correlations
  - High momentum components in nucleon wave function

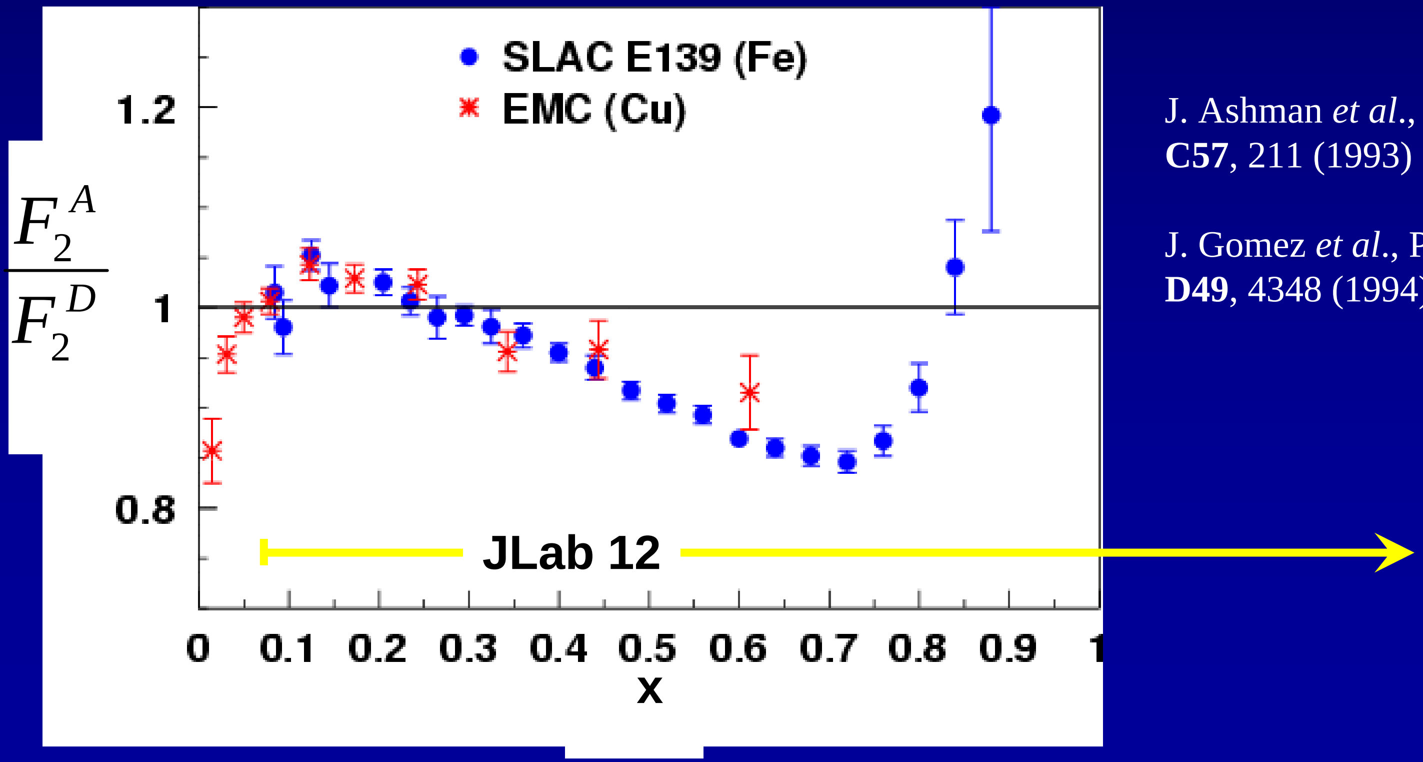


Quark Structure of Nuclei:

Origin of the EMC Effect

- Observation that structure functions are altered in nuclei shocked much of the HEP community 23 years ago
- ~1000 papers on the topic; models explain the curve by change of nucleon structure, but more data are needed to uniquely identify the origin

What is it that alters the quark momentum in the nucleus?



J. Ashman *et al*., Z. Phys. **C57**, 211 (1993)

J. Gomez *et al*., Phys. Rev. **D49**, 4348 (1994)